



## RESEARCH ARTICLE

# Validation of the Polar RS800CX for assessing heart rate variability during rest, moderate cycling and post-exercise recovery [version 1; peer review: 2 approved with reservations]

Kyriakos I. Tsitoglou<sup>1,2</sup>, Yiannis Koutedakis <sup>2,3</sup>, Petros C. Dinas <sup>2</sup>

<sup>1</sup>Institute of Cardiovascular Science, College of Medical and Dental Sciences, University of Birmingham, UK, Birmingham, B15 2TT, UK

<sup>2</sup>FAME Laboratory, Department of Exercise Science, University of Thessaly, Trikala, 42100, Greece

<sup>3</sup>Faculty of Education, Health and Wellbeing, University of Wolverhampton, Walsall, UK

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## Abstract

**Background:** Heart rate variability (HRV) is an autonomic nervous system marker that provides reliable information for both disease prevention and diagnosis; it is also used in sport settings. We examined the validity of the Polar RS800CX heart rate monitor during rest, moderate cycling, and recovery in considering the total of 24 HRV indices.

**Method:** A total of 32 healthy males (age=24.78±6.87 years, body mass index=24.48±3.13 kg/m<sup>2</sup>) completed a session comprised by three 20-minute time periods of resting, cycling at 60% of maximal heart rate, and recovery using a Polar RS800CX and an electrocardiogram (ECG) monitors. The HRV indices included time-domain, frequency-domain, Poincaré plot and recurrence plot. Bland–Altman plot analysis was used to estimate agreement between Polar RS800CX and ECG.

**Results:** We detected significant associations ( $r > 0.75$ ,  $p < 0.05$ ) in all HRV indices, while five out of 24 HRV indices displayed significant mean differences ( $p < 0.05$ ) between Polar RS800CX and ECG during the resting period. However, for the exercise and recovery periods, we found significant mean differences ( $p < 0.05$ ) in 16/24 and 22/24 HRV indices between the two monitors, respectively.




**Conclusion:** It is concluded that Polar RS800CX is a valid tool for monitoring HRV in individuals at resting conditions, but it displays inconsistency when used during exercise at 60% of maximal heart rate and recovery periods.

## Keywords

Heart Rate, HR, HRV, Polar RS800CX, Electrocardiogram, ECG

## Open Peer Review

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Any reports and responses or comments on the article can be found at the end of the article.		

**Corresponding author:** Petros C. Dinas ([petros.cd@gmail.com](mailto:petros.cd@gmail.com))

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## Introduction

Variations in successive heart rate (HR) and RR intervals [the peak of the Q, R, and S waves of the electrocardiogram (ECG)] simultaneously are described as heart rate variability (HRV), which is the conventionally accepted term to portray variations of RR intervals<sup>1</sup>. HRV is an autonomous nervous system (ANS) marker that may provide reliable information for both disease prevention and diagnosis<sup>2,3</sup>, while it is frequently applied to sport settings<sup>4,5</sup>. Furthermore, HRV can be used as a tool to identify physiological<sup>6,7</sup> and psychological<sup>8,9</sup> disorders, while it has been utilised for diagnosis in both clinical<sup>10</sup> and non-clinical studies<sup>11</sup>.

Regarding sport settings, HRV is primarily utilized to determine training loads<sup>12–14</sup> and endurance training adaptation<sup>15,16</sup>. The wide use of HRV in both clinical and basic research as a diagnostic criterion has resulted in increased production of HRV-related equipment and software. Reference gold standard such as Power Lab (AD Instruments, Australia) and Reynolds Pathfinder program (Reynolds Medical Limited, United Kingdom) were developed and used extensively when compared with other HR monitors (i.e. Polar)<sup>17</sup>. However, most of these innovations present disadvantages, such as difficulty of access and high cost<sup>18</sup>. To address these issues, more practical and cost-effective HRV tools were developed. The Polar RS800CX HR monitor (Polar Electro, Finland) was presented<sup>19–21</sup> as a valid HR monitor for HRV analysis during rest and stress conditions (e.g. exercise). To date, however, the wide spectrum of HRV indices (i.e. time and frequency domain, Poincaré and recurrence plot) has not been tested for validation in the Polar RS800CX. Also, the performance of Polar RS800CX in post-stress conditions has not been extensively investigated to date. Therefore, the purpose of this study was to assess the validity of Polar RS800CX in a large spectrum of HRV indices by comparing it with results gained using an ECG monitor during rest, exercise (cycling) and recovery.

## Methods

### Volunteers and experimental protocol

An informed written consent form was signed by and obtained from 32 apparently healthy males [age: 24.78±6.87, body mass index (BMI): 24.48±3.13 kg/m<sup>2</sup>] with no history of respiratory, metabolic, or cardiovascular conditions. Participants were recruited via flyers from the university population and the local community in Trikala, Thessaly, Greece between June and November 2012. Participants who responded to our flyer advertisement were then interviewed to determine eligibility and they were informed of all experimental procedures, associated risks, and discomforts, before providing written informed consent. The sample size was a sample of convenience. We included only male participants to avoid discomfort for females due to potential menstrual cycle. Ethical approval was obtained from the Ethics Review Board of the University of Thessaly (Protocol no. 469).

All participants visited the Environmental Physiology Laboratory in the Department of Exercise Science only once; they were instructed to refrain from food, caffeine and strenuous exercise 12 hours prior to the visit. Participants arrived at the physiology

laboratory between 7–8 am and they were subject to height (cm) and weight (kg) measurements via a Seca 220 (Hamburg, Germany) device. Subsequently, both a Polar RS800CX (Polar Electro Oy, Kempele, Finland) and a 12-lead ECG (Welch Allyn, CardioPerfect, New York, USA) monitors were adjusted to participants who then remained in a supine position on a comfortable bed and rested for 20 minutes in a quiet room at thermo-neutral conditions (22–24°C and 40–60% relative humidity). Immediately after the 20 minutes of resting, participants performed an aerobic exercise session on a cycle-ergometer (Monark, Ergonomic) at 60% of their maximum HR for 20 minutes. The maximum HR was calculated using Karvonen's formula<sup>22</sup>:  $[(220 - \text{age}) - \text{resting HR}] \times 0.60 + \text{resting HR}$ . At the end of the exercise period, the participants rested in a supine position for another 20 minutes for the post-exercise recovery period. To avoid any displacement, an investigator continuously checked the position of both the chest belt of the Polar RS800CX and the electrodes of the ECG, throughout the experiment. Data were collected throughout the experimental trial using both a Polar RS800CX and an ECG, as previously described<sup>23,24</sup>. For the Polar RS800CX the data downloaded and saved in a text format via **Polar ProTrainer 5** software, while the ECG data were collected via the Welch Allyn, **CardioPerfect Workstation 1.6.6** software.

### Analysis of heart rate variability indices

The raw data of the RR intervals of both the Polar RS800CX and the ECG were analysed using Premium Kubios HRV Analysis Software v1.1 (Biomedical Signal Analysis Group, University of Kuopio, Finland 2002). The retrieved HRV indices covered the time domain, frequency domain, Poincaré plot and recurrence plot indices (**Table 1–Table 3**).

### Statistical analyses

Normal distribution was checked via Shapiro-Wilk test. Due to non-normal distribution, a two-step transformation was used to normalise all HRV variables, given that the Bland–Altman method requires normally distributed data<sup>25</sup>. Pearson's correlation coefficient was employed to assess the associations and paired-sample t-tests to calculate the mean differences of HRV indices between the Polar RS800CX and the ECG during rest, exercise and recovery. The Bland–Altman plots and the 95% limits of agreement (95%LoA) were used to calculate agreement for all HRV indices during rest, exercise and recovery. We also calculated effect sizes between the Polar RS800CX and the ECG via the Cohen's *D* pooled effect size analysis for each HRV index during rest, exercise and recovery. We estimated the error rate of Mean RR intervals during rest, cycling and recovery, with the following equation:  $[(\text{Mean RR ECG} - \text{Mean RR RS800CX}) / \text{Mean RR ECG}] \times 100$ . Missing data were removed from the analysis, given that they were missing at random. The statistical analysis was completed using IBM SPSS v24 and the level of significance was set at  $p < 0.05$ .

## Results

The results of the Pearson correlation coefficient, paired-sample t-tests, 95%LoA and Cohen's *D* pooled effect size analyses appear in **Table 1** for the resting period, **Table 2** for the

**Table 1. Heart rate variability indices during the resting period.** Values for ECG and RS800CX presented as mean  $\pm$  standard deviation.

Variable	ECG <sup>‡</sup>	RS800CX <sup>‡</sup>	Correlation	Bias	LoA	Effect size
<b>Time domain</b>						
Mean RR (ms)	947.2 $\pm$ 151.6	944.9 $\pm$ 140.4	0.91*	2.2	-118.08–122.6	0.02
STDRR (ms)	85.2 $\pm$ 24.2	81.2 $\pm$ 28.04	0.92*	4.02	-18.06–26.1	0.15
Mean HR [1/min]	63.9 $\pm$ 19.5	66.7 $\pm$ 17.5	0.89*	-2.7	-20.4–14.8	0.15
STDHR [1/min]	6.1 $\pm$ 4.3	6.3 $\pm$ 2.9	0.89*	-0.3	-4.7–4.01	0.04
RMSSD (ms)	76.5 $\pm$ 32.2	67.5 $\pm$ 27.4	0.86*	7.1#	-24.4–38.7	<b>0.29 (small)</b>
NN50 [beats]	210.9 $\pm$ 88.6	200.9 $\pm$ 89.4	0.95*	4.9	-49.5–59.4	0.11
pNN50 (%)	35.1 $\pm$ 14.4	33.6 $\pm$ 15.3	0.92*	0.6	-11.07–12.4	0.10
HRV triangular	17.1 $\pm$ 4.2	17 $\pm$ 5.08	0.92*	0.2	-3.7–4.2	0.02
TINN [ms]	228.9 $\pm$ 244.4	238.2 $\pm$ 187.8	0.79*	-9.2	-304.7–286.1	0.04
<b>Frequency domain</b>						
LF (ms <sup>2</sup> )	55.3 $\pm$ 14.9	55.7 $\pm$ 15.3	0.86*	-0.4	-16.2–15.3	0.03
HF (ms <sup>2</sup> )	44.5 $\pm$ 14.5	43 $\pm$ 14.2	0.82*	0.5	-16.2–17.3	0.10
LF/HF [-]	1.7 $\pm$ 2.3	0.07 $\pm$ 4.8	0.85*	1.8#	-4.2–7.8	<b>0.45 (small)</b>
<b>Poincaré plot</b>						
SD1 [ms]	54.7 $\pm$ 21.3	48.9 $\pm$ 20.05	0.93*	4.5#	-10.7–19.9	<b>0.28 (small)</b>
SD2 [ms]	106.2 $\pm$ 26.9	100.8 $\pm$ 30.9	0.92*	5.4#	-18.9–29.8	0.19
SamPEn [-]	1.4 $\pm$ 0.3	1.4 $\pm$ 0.3	0.92*	0.03	-0.2–0.2	0.11
ApEn [-]	1.2 $\pm$ 0.2	1.2 $\pm$ 0.2	0.94*	0.03#	-0.1–0.2	0.13
DFA_a1 [-]	1.0 $\pm$ 0.2	1.0 $\pm$ 0.2	0.86*	0.01	-0.2–0.2	0.06
DFA_a2 [-]	0.9 $\pm$ 0.1	0.9 $\pm$ 0.1	0.80*	0.0004	-0.2–0.2	0.00
<b>Recurrence plot</b>						
Lmin [beats]	14.3 $\pm$ 34.3	16.1 $\pm$ 40.02	0.88*	-1.8	-38.7–35.1	0.05
Lmax [beats]	279.2 $\pm$ 201.3	297.8 $\pm$ 205.7	0.93*	-18.6	-172.7–135.5	0.09
REC [%]	34.7 $\pm$ 9.0	34.3 $\pm$ 9.2	0.75*	0.4	-12.3–13.1	0.05
DET [%]	97.7 $\pm$ 0.8	97.8 $\pm$ 0.7	0.86*	-0.09	-0.9–0.7	0.12
ShanEn [-]	3.3 $\pm$ 0.4	3.3 $\pm$ 0.5	0.87*	-0.04	-0.5–0.4	0.09
D2 [-]	2.8 $\pm$ 1.0	2.6 $\pm$ 1.1	0.78*	0.1	-1.2–1.6	0.14

\*Significant association between ECG and Polar RS800 CX. #Significant mean differences between ECG and Polar RS800 CX. ‡n=32. ECG, electrocardiogram; MeanRR [ms], standard deviation of all RR intervals; STDRR [ms], standard deviation of normal to normal R-R intervals; MeanHR [1/min], The mean heart rate; STDHR [1/min], Standard deviation of instantaneous heart rate values; RMSSD [ms], root mean square of differences; pNN50, proportion of differences between adjacent NN intervals of more than 50ms; NN50 [beats], number of NN intervals that differ more than 50 ms; HRV triangular index [-], The integral of the RR interval histogram divided by the height of the histogram; TINN [ms], Baseline width of the RR interval histogram; LF (ms<sup>2</sup>), low frequency; HF (ms<sup>2</sup>), high frequency; LF/HF [-], Ratio LF [ms<sup>2</sup>]/HF [ms<sup>2</sup>]; SD1 [ms], represents the dispersion of the points along the line of identity and is thought to be an index of the instantaneous beat-to-beat variability of the data; SD2 [ms], represents the dispersion of the points along the line of identity and is thought to represent the slow variability of heart rate; SamPEn [-], complexity of NN series; ApEn, approximate entropy of the complexity or irregularity of the signal; DFA, Detrended fluctuation analysis of the correlation within the HRV signal divided into short-term and long-term fluctuations; Lmin (beats), mean line length; Lmax (beats), maximum line length; REC [%], recurrence rate; DET [%], determinism; ShanEn [-], shannon entropy consider the lengths of the diagonal lines; D2 [-], correlation dimension.

exercise period and **Table 3** for the recovery period. **Dataset 1** contains all raw data obtained using both measurement methods<sup>26</sup>. The Bland–Altman plots for the resting, exercise and recovery periods, can be found in **Supplementary File 1**. Missing values were removed from the analysis and the final number of participants for each HRV index appears in **Table 1**

for the resting period, **Table 2** for the exercise period and **Table 3** for the recovery period.

During the resting period, Polar RS800CX showed significant correlations ( $r>0.75$ ,  $p<0.05$ ) with the ECG in all studied HRV indices. We found one time domain (RMSSD), one frequency

**Table 2. Heart rate variability parameters during the exercise period.** Values for ECG and Polar RS 800CX presented as mean  $\pm$  standard deviation.

Variable	ECG <sup>‡</sup>	RS800CX <sup>‡</sup>	Correlation	Bias	LoA	Effect size
<b>Time domain</b>						
Mean RR (ms)	552.2 $\pm$ 15.8	749.5 $\pm$ 88.2	0.05	-197.2 <sup>#</sup>	-547.4–153	<b>1.51 (large)</b>
STDRR(ms)	41.9 $\pm$ 27.4, n=31	107.6 $\pm$ 25.8	-0.42 <sup>*</sup>	-65.6 <sup>#</sup>	-153.8–22.4	<b>2.48 (large)</b>
Mean HR [1/min]	117.3 $\pm$ 14.6, n=31	92.5 $\pm$ 10.8	0.24	24.7 <sup>#</sup>	-6.6–56.1	<b>1.91 (large)</b>
STDHR [1/min]	11.2 $\pm$ 2.9, n=31	12.2 $\pm$ 2.7	0.27	-0.9	-7.7–5.7	<b>0.34 (small)</b>
RMSSD (ms)	12.2 $\pm$ 27.3, n=31	48.2 $\pm$ 23.6	0.32	-35.9 <sup>#</sup>	-94.2–22.2	<b>1.39 (large)</b>
NN50 [beats]	19.4 $\pm$ 78.1, n=31	132.3 $\pm$ 75.8	0.22	-112.9 <sup>#</sup>	-301.37to 75.5	<b>1.40 (large)</b>
pNN50 (%)	-0.08 $\pm$ 12.2, n=31	20.6 $\pm$ 12.7	0.24	-20.7 <sup>#</sup>	-50.7–9.3	<b>1.64 (large)</b>
HRV triangular	7.3 $\pm$ 3.9, n=31	14.8 $\pm$ 3.8	0.30	-7.4 <sup>#</sup>	-16.5–1.5	<b>1.92 (large)</b>
TINN[ms]	356.1 $\pm$ 311.9, n=31	455.2 $\pm$ 130.2	0.23	-99.1	-703.8–505.5	<b>0.40 (small)</b>
<b>Frequency domain</b>						
LF(ms <sup>2</sup> )	64.2 $\pm$ 12.8, n=31	64.4 $\pm$ 10.4	-0.07	-0.1	-33.7–33.3	0.07
HF (ms <sup>2</sup> )	35.2 $\pm$ 13.9, n=31	34.9 $\pm$ 10.6	0.09	0.2	-32.5–32.9	0.01
LF/HF[-]	3.2 $\pm$ 1.7, n=31	3.7 $\pm$ 3.5	0.24	-0.4	-7.5–6.5	<b>0.24 (small)</b>
<b>Poincaré plot</b>						
SD1[ms]	8.3 $\pm$ 18.8, n=31	34.4 $\pm$ 17.1	0.34	-26.06 <sup>#</sup>	-66.7–14.6	<b>1.42 (large)</b>
SD2[ms]	57.6 $\pm$ 36.3, n=31	149 $\pm$ 34.2	-0.31	-91.3 <sup>#</sup>	-203.4–20.7	<b>2.61 (large)</b>
SamplEn [-]	0.8 $\pm$ 0.2, n=31	0.7 $\pm$ 0.3	0.56 <sup>*</sup>	0.02	-0.5–0.6	0.11
ApEn[-]	0.8 $\pm$ 0.1, n=31	0.7 $\pm$ 0.2	0.65 <sup>*</sup>	0.09 <sup>#</sup>	-0.2–0.4	<b>0.48 (small)</b>
DFA_a1[-]	0.9 $\pm$ 0.2, n=31	1.1 $\pm$ 0.1	0.08	-0.2 <sup>#</sup>	-0.8–0.3	<b>1.18 (large)</b>
DFA_a2[-]	0.9 $\pm$ 0.1, n=31	1.0 $\pm$ 0.1	0.55 <sup>*</sup>	-0.1 <sup>#</sup>	-0.4–0.2	<b>0.64 (moderate)</b>
<b>Recurrence plot</b>						
Lmin [beats]	61.7 $\pm$ 19.9, n=31	66.8 $\pm$ 25.7	0.51 <sup>*</sup>	-5.02	-50.5–40.4	<b>0.23 (small)</b>
Lmax [beats]	691.2 $\pm$ 254.4, n=31	614.5 $\pm$ 147.6	0.30	76.7	-418.3–571.8	<b>0.35 (small)</b>
REC [%]	49.9 $\pm$ 7.5, n=31	47.6 $\pm$ 8.5	-0.12	2.2	-21.3–25.8	<b>0.23 (small)</b>
DET [%]	99.6 $\pm$ 0.8, n=31	99.1 $\pm$ 0.9	0.47 <sup>*</sup>	0.4 <sup>#</sup>	-1.3–2.3	<b>0.53 (moderate)</b>
ShanEn[-]	4.2 $\pm$ 0.3, n=31	4.1 $\pm$ 0.4	0.31	0.08	-0.8–1.06	0.06
D2[-]	0.7 $\pm$ 0.6, n=31	1.8 $\pm$ 0.5	-0.06	-1.1 <sup>#</sup>	-2.9–0.7	<b>1.73 (large)</b>

\*Significant association between ECG and Polar RS800 CX. # Significant mean differences between ECG and Polar RS800 CX. ‡n=32 unless indicated. ECG, electrocardiogram; MeanRR [ms], standard deviation of all RR intervals; STDRR [ms], standard deviation of normal to normal R-R intervals; MeanHR [1/min], The mean heart rate; STDHR [1/min], Standard deviation of instantaneous heart rate values; RMSSD [ms], root mean square of differences; pNN50, proportion of differences between adjacent NN intervals of more than 50ms; NN50 [beats], number of NN intervals that differ more than 50 ms; HRV triangular index [-], The integral of the RR interval histogram divided by the height of the histogram; TINN [ms], Baseline width of the RR interval histogram; LF (ms<sup>2</sup>), low frequency; HF (ms<sup>2</sup>), high frequency; LF/HF [-], Ratio LF [ms<sup>2</sup>]/HF [ms<sup>2</sup>]; SD1 [ms], represents the dispersion of the points along the line of identity and is thought to be an index of the instantaneous beat-to-beat variability of the data; SD2 [ms], represents the dispersion of the points along the line of identity and is thought to represent the slow variability of heart rate; SamplEn [-], complexity of NN series; ApEn, approximate entropy of the complexity or irregularity of the signal; DFA, Detrended fluctuation analysis of the correlation within the HRV signal divided into short-term and long-term fluctuations; Lmin (beats), mean line length; Lmax (beats), maximum line length; REC [%], recurrence rate; DET [%], determinism; ShanEn [-], shannon entropy consider the lengths of the diagonal lines; D2 [-], correlation dimension.

domain (LF/HF) and three Poincaré plot (SD1, SD2, ApEn) HRV indices, to show significant mean differences ( $p < 0.05$ ) between Polar RS800CX and the ECG. Also, one time domain (RMSSD), one frequency domain (LF/HF) and one Poincaré plot (SD1) HRV indices showed small effect sizes (0.28–0.45) between the Polar RS800CX and the ECG (Table 1). Finally,

during rest, the error rate of Mean RR intervals obtained from Polar RS800CX and the ECG, was 0.3%.

In the exercise period, one time domain (STDRR) ( $r = 0.42$ ,  $p < 0.05$ ), three Poincaré plot [SamplEn ( $r = 0.56$ ,  $p < 0.05$ ), ApEn ( $r = 0.65$ ,  $p < 0.05$ ), DFAa2 ( $r = 0.55$ ,  $p < 0.05$ )] and two recurrence

**Table 3. Heart rate variability indices during the recovery period.** Values for ECG and Polar RS 800CX presented as mean  $\pm$  standard deviation, n=number of cases.

Variable	ECG*	RS800CX	Correlation	Bias	LoA	Effect size
<b>Time domain</b>						
Mean RR (ms)	807 $\pm$ 87.08	512 $\pm$ 112.2, n=27	0.36	294.6#	70.7–518.5	<b>2.41 (large)</b>
STDRR (ms)	72.7 $\pm$ 21.5	56.8 $\pm$ 28.5, n=27	0.02	15.9#	-53.2–85.1	<b>0.57 (moderate)</b>
Mean HR [1/min]	81.5 $\pm$ 10.4	121.8 $\pm$ 13.9, n=27	0.29	-40.2#	-69.3–11.1	<b>2.99 (large)</b>
STDHR [1/min]	6.7 $\pm$ 3.9	11.1 $\pm$ 4.7, n=27	-0.20	-4.4#	-17.6–8.8	<b>0.68 (moderate)</b>
RMSSD (ms)	53.2 $\pm$ 30.6	2 $\pm$ 20.1, n=27	0.39*	51.1#	-6.06–108.4	<b>1.31 (large)</b>
NN50 [beats]	136.6 $\pm$ 100.4	-1.9 $\pm$ 61.5, n=27	0.38	138.6#	-48.8–326.1	<b>1.20 (large)</b>
pNN50 (%)	23.4 $\pm$ 18.3	-0.5 $\pm$ 12.3, n=27	0.59*	23.9#	-4.9–52.9	<b>1.19 (large)</b>
HRV triangular	14.1 $\pm$ 4.2	6.2 $\pm$ 3.6, n=27	0.31	7.9#	-1.1–17	<b>1.63 (large)</b>
TINN [ms]	380.6 $\pm$ 180.2	285.5 $\pm$ 283.7, n=27	0.36	95.04	-444.4–634.5	<b>0.44 (small)</b>
<b>Frequency domain</b>						
LF (ms <sup>2</sup> )	65.7 $\pm$ 16.2	78.9 $\pm$ 12.9, n=27	0.20	-13.2#	-49.7–23.3	<b>0.80 (large)</b>
HF (ms <sup>2</sup> )	34.7 $\pm$ 15.7	21.3 $\pm$ 12.2, n=27	0.22	13.4#	-21.1–47.9	<b>0.87 (large)</b>
LF/HF [-]	2.8 $\pm$ 2	8.3 $\pm$ 4.4, n=27	0.13	-5.4#	-14.4–3.6	<b>1.57 (large)</b>
<b>Poincaré plot</b>						
SD1 [ms]	37.6 $\pm$ 22.8	2.4 $\pm$ 15.4, n=28	0.17	35.1#	-14.3–84.7	<b>1.30 (large)</b>
SD2 [ms]	94.4 $\pm$ 26.3	80 $\pm$ 40.03, n=27	0.01	14.4	-78.6–107.6	<b>0.42 (small)</b>
SamplEn [-]	1.2 $\pm$ 0.3	0.6 $\pm$ 0.3, n=27	0.21	0.6#	-0.1–1.4	<b>1.40 (large)</b>
ApEn [-]	1.1 $\pm$ 0.2	0.6 $\pm$ 0.2, n=27	0.15	0.4#	-0.1–1.03	<b>1.42 (large)</b>
DFA_a1 [-]	1.1 $\pm$ 0.2	1.3 $\pm$ 0.2, n=27	0.22	-0.1#	-0.7–0.3	<b>0.56 (moderate)</b>
DFA_a2 [-]	0.8 $\pm$ 0.1	1.1 $\pm$ 0.1, n=27	0.29	-0.2#	-0.6–0.1	<b>1.31 (large)</b>
<b>Recurrence plot</b>						
Lmin [beats]	19.8 $\pm$ 25.05	70.8 $\pm$ 29.8, n=27	0.41*	-50.9#	-109.8–7.9	<b>1.35 (large)</b>
Lmax [beats]	380.4 $\pm$ 243.1	904.9 $\pm$ 171.5, n=27	0.29	-524.5#	-1019.5–29.5	<b>1.92 (large)</b>
REC [%]	38.2 $\pm$ 9.5	53.6 $\pm$ 8.07, n=27	0.43*	-15.3#	-33.9–3.1	<b>1.34 (large)</b>
DET [%]	98.4 $\pm$ 1.04	99.9 $\pm$ 0.7, n=27	0.40*	-1.4#	-3.4–0.4	<b>1.08 (large)</b>
ShanEn [-]	3.5 $\pm$ 0.5	4.4 $\pm$ 0.4, n=27	0.35	-0.9#	-2.01–0.1	<b>1.47 (large)</b>
D2 [-]	2.3 $\pm$ 1.3	0.4 $\pm$ 0.7, n=27	-0.09	1.8#	-1.1–4.9	<b>1.74 (large)</b>

\*Significant association between ECG and Polar RS800 CX. #Significant mean differences between ECG and Polar RS800 CX. n=32. MeanRR [ms], standard deviation of all RR intervals; STDRR [ms], standard deviation of normal to normal R-R intervals; MeanHR [1/min], The mean heart rate; STDHR [1/min], Standard deviation of instantaneous heart rate values; RMSSD [ms], root mean square of differences; pNN50, proportion of differences between adjacent NN intervals of more than 50ms; NN50 [beats], number of NN intervals that differ more than 50 ms; HRV triangular index [-], The integral of the RR interval histogram divided by the height of the histogram; TINN [ms], Baseline width of the RR interval histogram; LF (ms<sup>2</sup>), low frequency; HF (ms<sup>2</sup>), high frequency; LF/HF [-], Ratio LF [ms<sup>2</sup>]/HF [ms<sup>2</sup>]; SD1 [ms], represents the dispersion of the points along the line of identity and is thought to be an index of the instantaneous beat-to-beat variability of the data; SD2 [ms], represents the dispersion of the points along the line of identity and is thought to represent the slow variability of heart rate; SamplEn [-], complexity of NN series; ApEn, approximate entropy of the complexity or irregularity of the signal; DFA, Detrended fluctuation analysis of the correlation within the HRV signal divided into short-term and long-term fluctuations; Lmin (beats), mean line length; Lmax (beats), maximum line length; REC [%], recurrence rate; DET [%], determinism; ShanEn [-], shannon entropy consider the lengths of the diagonal lines; D2 [-], correlation dimension.

plot [Lmin (r=0.51, p<0.05), DET (r=0.47, p<0.05)] HRV indices showed significant correlations between Polar RS800CX and the ECG. However, we detected seven out of nine time domain, five out of six Poincaré plot and two out of six recurrence plot HRV indices to display significant mean differences (p<0.05) between Polar RS800CX and the ECG. Small to large effect sizes (0.23–2.61) found in 20 out of the

24 examined HRV indices between Polar RS800CX and the ECG (Table 2). Finally, during exercise, the error rate of Mean RR intervals obtained from the Polar RS800CX and the ECG, was 28.1%.

During the recovery period, two time domain (RMSSD, pNN50) and three recurrence plot (Lmin, REC, DET) HRV



indices showed significant correlations ( $r=0.39-0.59$ ,  $p<0.05$ ) between Polar RS800CX and the ECG. In total, eight out of nine time domain, all the frequency domain, five out of six Poincaré plot and all the recurrence plot HRV indices showed significant mean differences ( $p<0.05$ ) between Polar RS800CX and the ECG. All the HRV indices showed small to large effect sizes (0.42–2.99) between Polar RS800CX and the ECG (Table 3). Finally, during recovery, the error rate of Mean RR intervals obtained from Polar RS800CX and the ECG, was 68.3%.

**Dataset 1. Validation of Polar RS800CX for heart rate variability measurements**

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## Discussion

The aim of the current study was to assess the validity of Polar RS800CX in a large spectrum of HRV parameters by comparing it with a 12-lead ECG monitor during rest, moderate cycling and recovery. We found that all the HRV indices ( $n=24$ ) based on Polar RS800CX are correlated, while only five HRV indices displayed mean differences with the ECG HRV indices during the resting period. This confirms recent data showing that Polar RS800CX is valid for resting HRV measurements<sup>19–21,27,28</sup>. However, we confirmed for the first time that this is the case for the wide spectrum of HRV indices. Also, the majority of the previous studies showed that other Polar HR monitors (i.e. S810, 810s, S810i, V800) showed good agreement with ECG in detecting RR intervals in supine and standing positions of adult individuals<sup>5,18,23</sup>, and children<sup>24,29</sup>. One previous study nevertheless, showed a bias of the Polar S810 in detecting HRV indices in supine and standing positions during rest<sup>30</sup>.

During the exercise period, Polar RS800CX displayed a disagreement with the ECG in HRV indices. The error rate of Mean RR intervals obtained from Polar RS800CX and the ECG in our study was 28.1%. This is significantly higher than the error rate (0.71%) of RR intervals in a previous similar study examined the validity of Polar V800 during exercise<sup>31</sup>. Also, a previous study showed similar bias of Polar S810 HR monitor during exercise in high frequency (HF) HRV index at intensities  $>60\%$  of  $\text{VO}_2$  max and low frequency (LF) HRV index at intensities 80–100% of  $\text{VO}_2$  max, even though the HR monitor found relatively valid in exercise intensities  $<60\%$  of  $\text{VO}_2$  max<sup>29</sup>. Subsequent studies showed the Polar S810 had no bias during exercise<sup>18</sup> and Polar V800 during high endurance running<sup>31</sup>. Reasons that Polar HR monitors may display bias in measuring HRV indices during exercise include: a) the insecure

placement of the elastic band on the thorax; b) the movement of the ECG electrodes during exercise, given that our participants were healthy and they showed no arrhythmia; c) the corresponding transmission of the data from the HR monitors; and d) changes of R-wave detection and the peak detection algorithms used<sup>29,32–35</sup>.

Regarding the recovery period, the existing evidence is rather scarce. In our study, we found that the Polar RS800CX displayed bias in the recovery period. For instance, the error rate of mean RR intervals obtained from the Polar RS800CX and the ECG, was 68.3%. Perhaps some of the reasons reported above for the displayed bias during stress/exercise conditions may also apply to the recovery stage.

A limitation of the current study might be the small sample size of participants. However, a post-measurement online power calculation (DSS Research), using as an index the resting RS800CX Mean RR HRV index of the current study and the resting RS800CX Mean RR HRV index from a previous similar study<sup>19</sup>, showed 100% of statistical power ( $n=32$ ) in our study. Another limitation might be that only males participated in this study and, therefore, our outcomes should be treated with caution when apply to females. However, we used a well-established statistical approach, as previously described<sup>19,21,23,31</sup>. Finally, even though an investigator continuously checked the displacement of the chest belt and the electrodes of the Polar RS800CX and the ECG respectively, there is a possibility of a displacement due to sweating during the exercise and recovery periods, as previously suggested<sup>36</sup>.

We conclude that Polar RS800CX found to be a valid tool for monitoring HRV during resting periods, but not for assessments during exercise at intensity of  $60\% \text{VO}_2$  max and recovery periods. Testing the validity of devices such as Polar monitors in stressful (hot/cold or extreme) conditions such as exercise, requires further scientific attention, given that these instruments could provide a cost-effective method for monitoring HRV.

## Data availability

Dataset 1. Validation of Polar RS800CX for heart rate variability measurements. DOI: <https://doi.org/10.5256/f1000research.16130.d216722><sup>36</sup>.

## Grant information

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## Supplementary material

Supplementary File 1. Bland–Altman plots for resting, cycling and recovery periods.

[Click here to access the data.](#)

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